Transition fixes

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Fixing transition oscillations

- Recall at transition, there is no bucket and all particles essentially have the same revolution frequency independent of energy and the bunch is the shortest during the ramp.
  - Highest space charge effect.
- The longitudinal quadrupole oscillation arises from the beam from two phenomena
  - No space charge: The beam is very short at transition, in fact, at its shortest. This does not match the subsequent bucket that is formed after transition and thus there is a bunch length oscillations after transition.
  - With space charge: Space charge is “focusing” after transition. This is also known as the “negative mass” effect. (See later slide). Space charge is “defocusing” before transition. After transition, the bunch is over-focused and thus bunch length oscillations occur on top of bucket mis-match.
- Is there a transition problem from space charge????
  - I cannot reproduce YangXi's simulation results. (Chandra also cannot at this time)

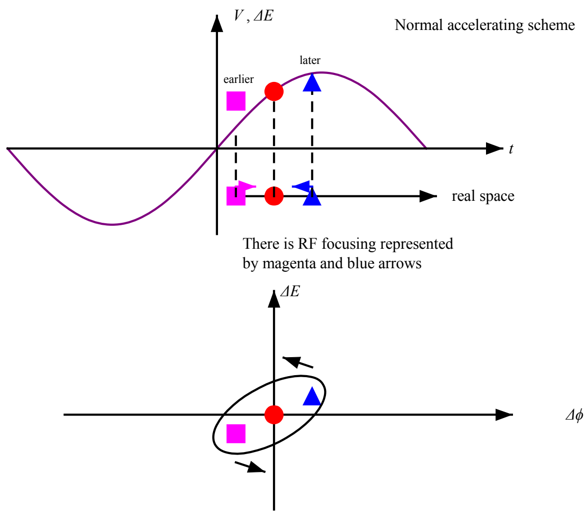
Recall negative mass

- When 2 charges are close together above transition, the early charge gets a positive energy kick and the later charge gets a negative energy kick. Since we are above transition, the early charge gets a longer orbital period and the late charge gets a shorter orbital period. Therefore, they get closer together! Thus “focusing”. Opposite happens below transition. See Edwards & Syphers pg 181.

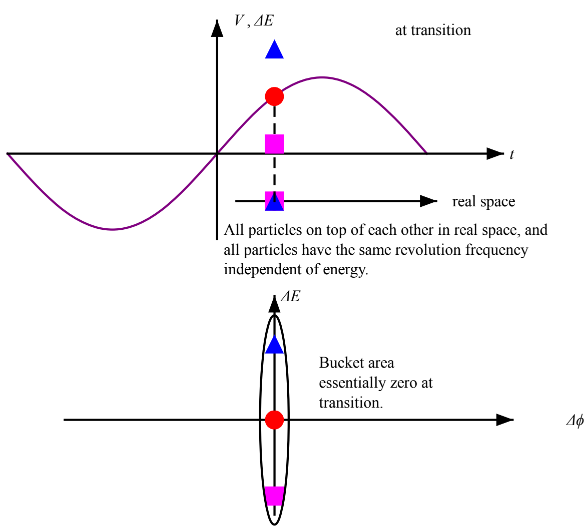
Cures for quadrupole oscillations

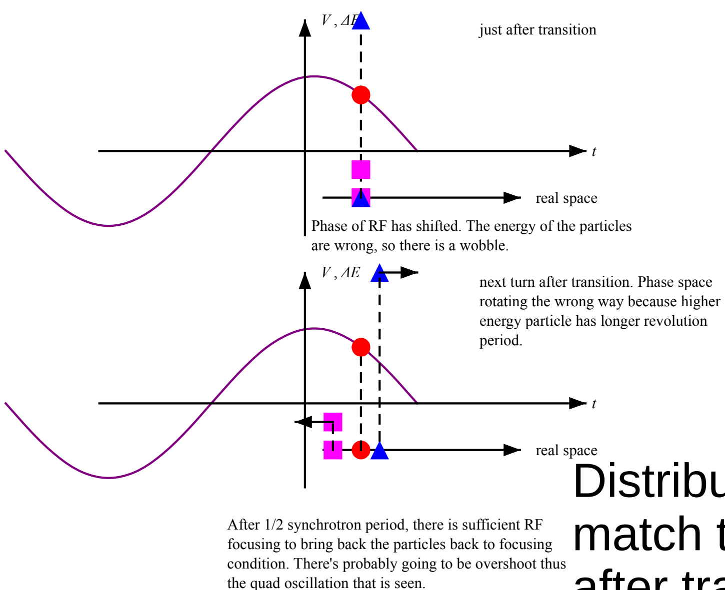
- Bhat et al method (focus-free method) for fixing bucket mismatch
  - Flatten the voltage just before and after transition with 3rd harmonic. (We can also do this with 2nd harmonic as well).
    - This requires a phase shift of the RF so that the synchronous particle is in the middle of the voltage plateau.
    - Give all the particles the same energy kick.
  - The beam is “drifts” before and after transition but in the opposite directions because there is no focusing, i.e. beam is like free particles after energy offset is taken out.
- Y. Xi et al method for fixing space charge defocusing/focusing with “over-focusing” before transition
  - Over-focus the beam just before transition to counter the “defocusing” of beam from space charge at transition and this “over-focus” becomes “defocusing” after transition to counter the focusing of the space charge force.
  - Use more volts to get a steeper slope
    - She used 3rd harmonic to add more volts and slope to make it comparable to 45% more volts on fundamental.
    - We will use 2nd harmonic to add more volts and slope. At 100 kV, we can get comparable volts but not slope.
- Essentially, both methods rely on manipulating the focusing of the beam before and after transition.

Normal transition



We assume that the distribution is "matched" before transition.

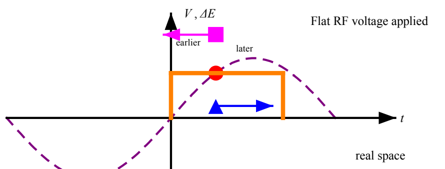




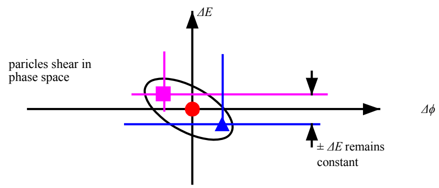
Distribution does not match to the bucket after transition.

Comic of “focus free” method

Before transition, distribution considered "matched" to bucket

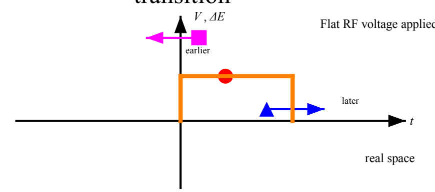


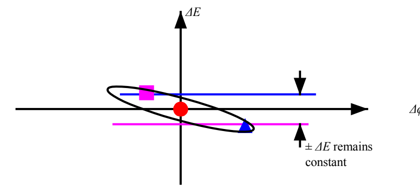
All the particles get the same kick, so, it can be thought of that the particles are drifting, since in phase space, we tkae out the energy gained by the reference particle



Beam looks frozen in place. There is **NO RF focusing** with a flat voltage, i.e. focus free. $\pm\Delta E$ and $\pm\Delta\phi$ remains constant during this time.

Just before transition

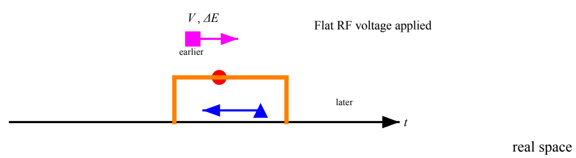


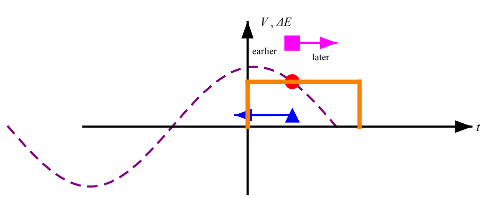


Everything is frozen at transition

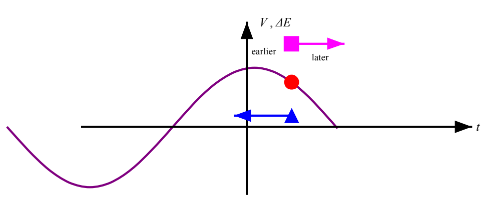
At transition, everthing is frozen. There is no focusing or defocusing, all particles have the same revolution frequency independent of energy

Just after transition

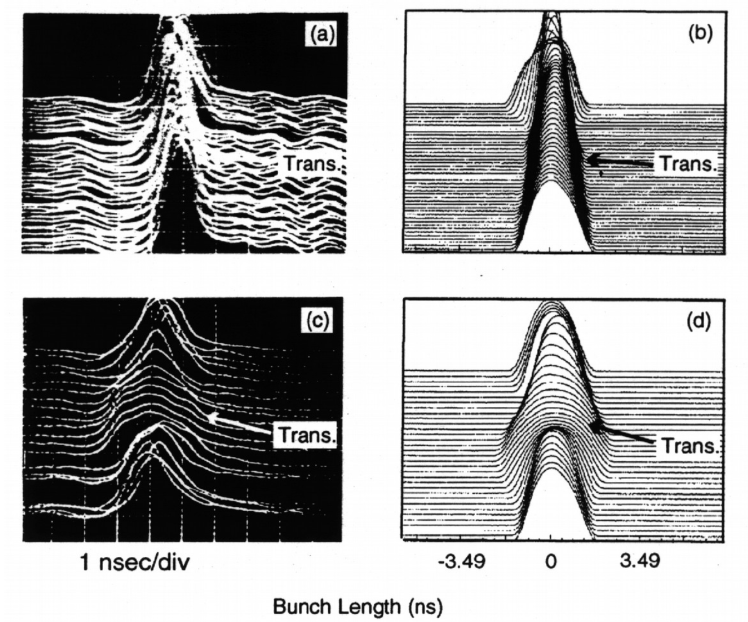




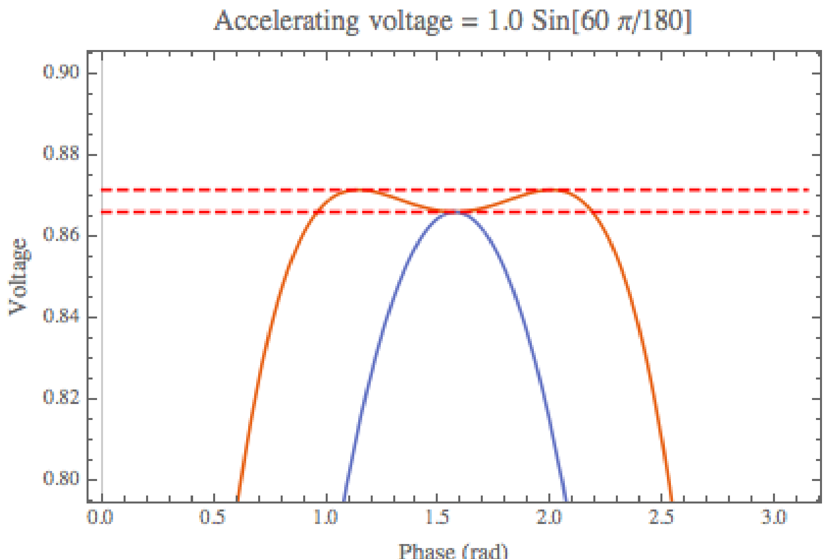
At some time later, the distribution looks like distribution before transition



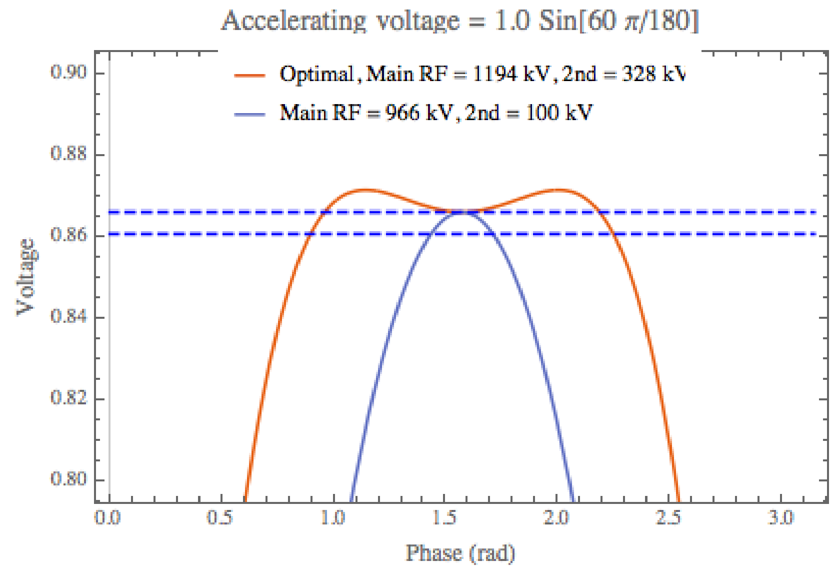
Turn normal RF back on again.



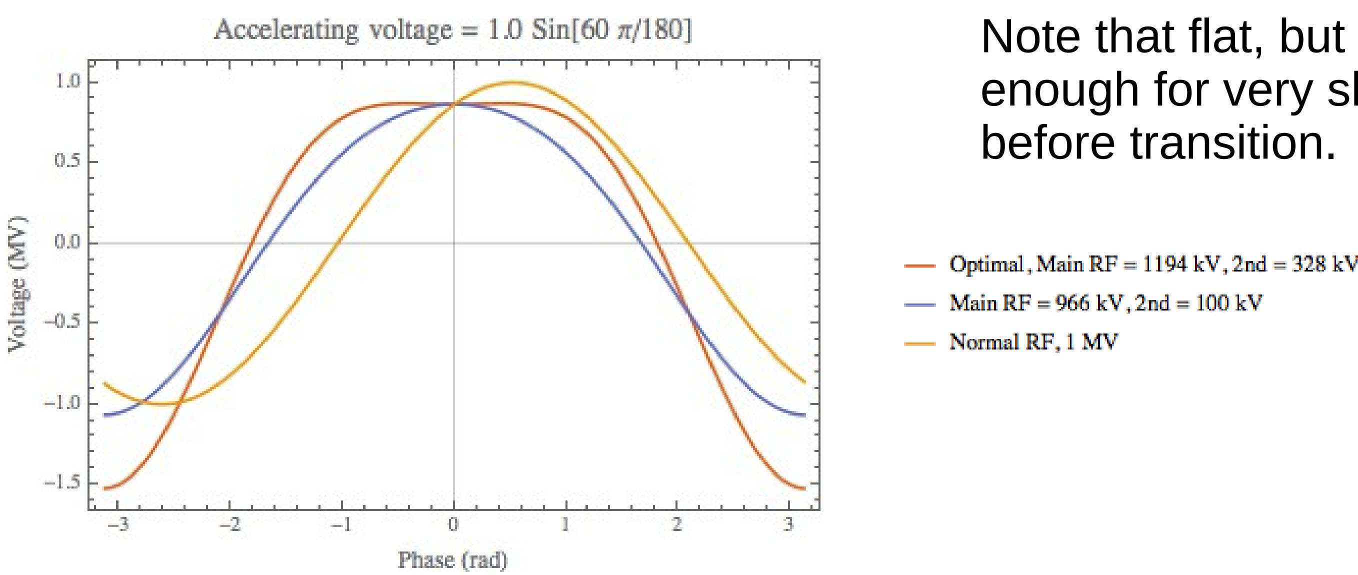
How flat can the voltage be with 2nd harmonic at 100 kV



0.6% variation, bunch length is 153 deg.

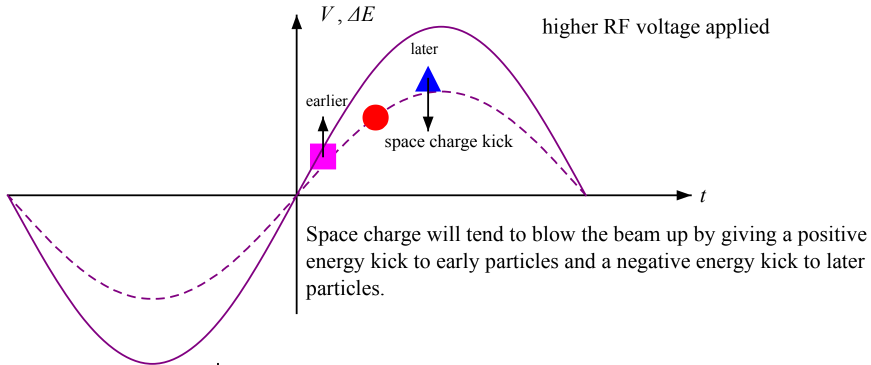


0.6% variation, bunch length is 15.8 deg.

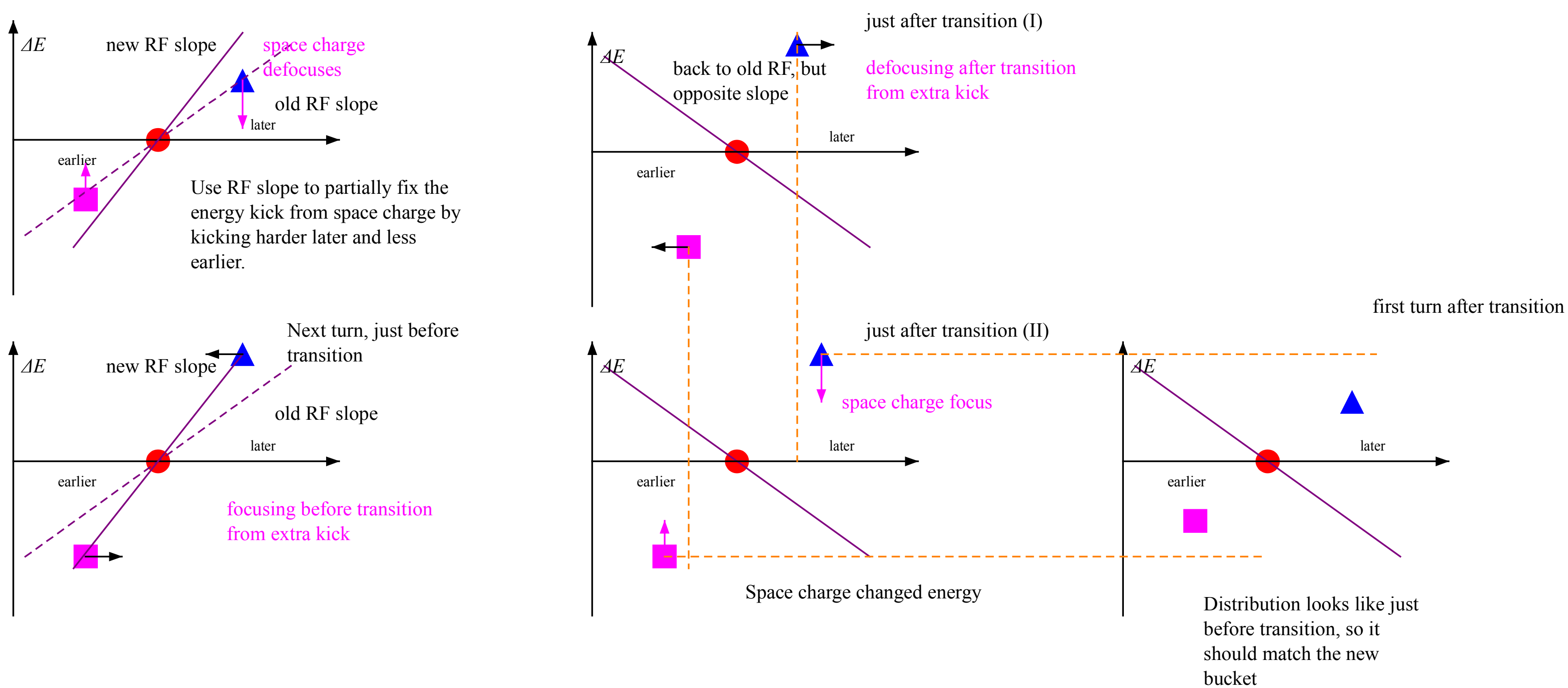


Note that flat, but could be good enough for very short bunches before transition.

Comic of “overfocus” method



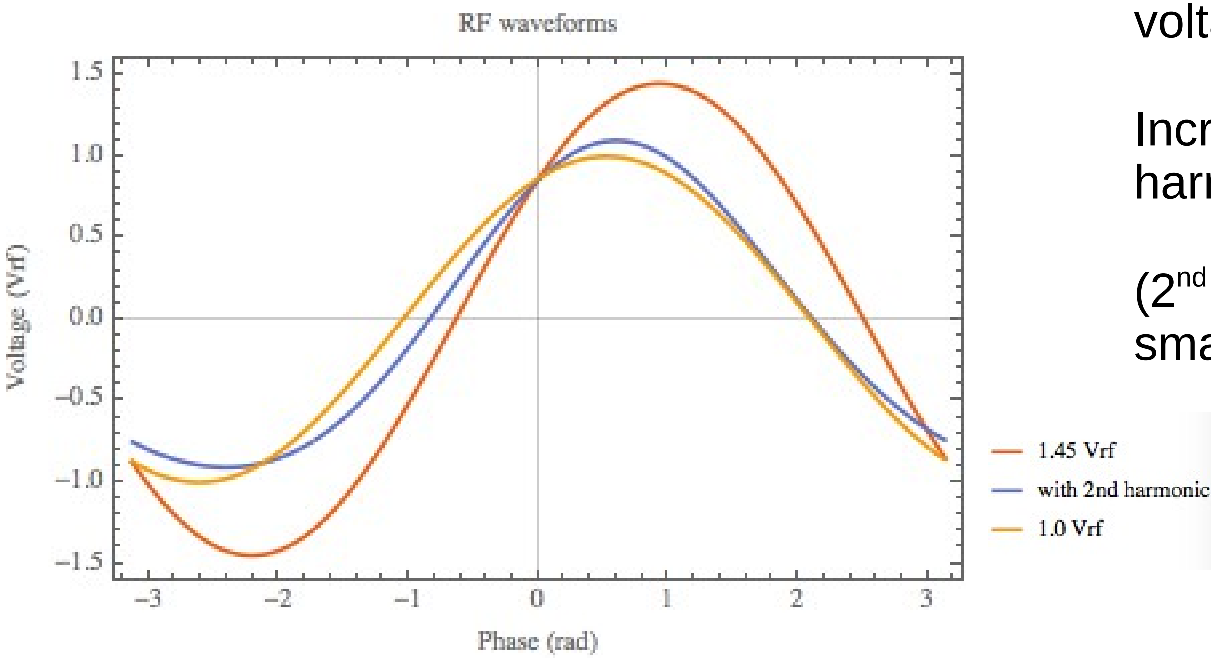
Must have enough “slope” to compensate for the ΔE changes from space charge before and after transition.



“Overfocusing” method

- What I want is increased slope instead of what Yang Xi did where she also increased voltage+slope. So how much more slope at the synchronous phase can I get with the same accelerating voltage of the main RF with the 2nd harmonic added?

Note: in Yang Xi's writeup RF3rd-inj-TC.pdf she uses 28 deg as synchronous phase. I will used 60 deg instead.

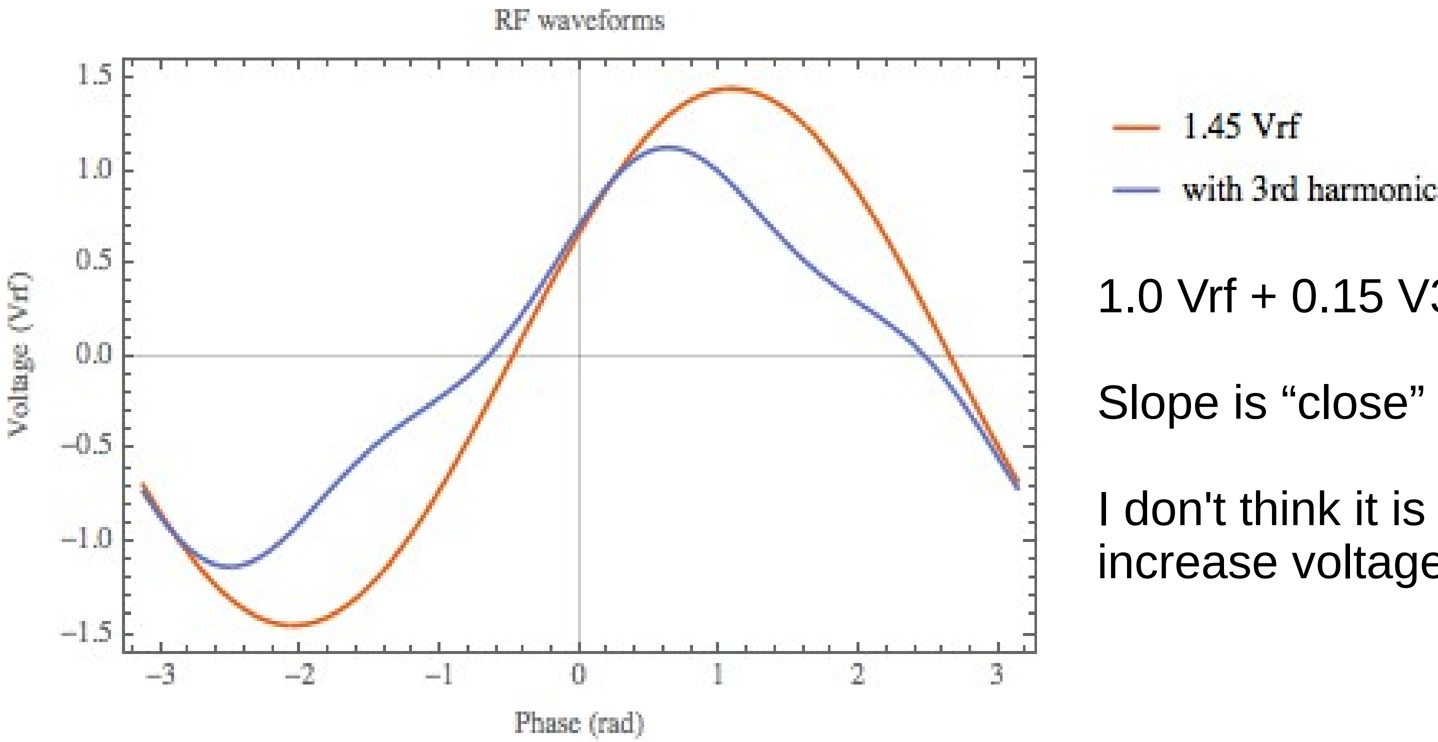


Slope of 1.0Vrf at 60 deg phase = 0.5
1.0Vrf with 2nd harmonic slope = 0.76
1.45 Vrf slope @ 36.6 deg phase = 1.16 (to give the same accelerating voltage)

Increase in slope is 52% between 2nd harmonic and fundamental only.

(2nd harmonic + normal RF) is 34% smaller than 1.45 Vrf @ 36.6 deg

Comparison with 3rd harmonic



1.0 Vrf + 0.15 V3rd harmonic.

Slope is “close” to 1.45 Vrf slope.

I don't think it is necessary to increase voltage to match 1.45 Vrf.

Hybrid Focusing

- Focus free method does not work very well with space charge dominated beam, not clear that at 100 kV we have enough “flat” region”.
- Over-focusing method, probably does not have enough slope at 100 kV.
- Consider combining both methods to see if this works better than using each one alone.
  - Start overfocusing to try to compensate as much as possible the space charge “defocusing” and “focusing” before transition
  - Then flatten RF voltage to allow the distribution to drift to get longer bunch before transition.
  - Wait for bunch to match bucket before turning off flat RF voltage.

Conclusion

- Work continues to see whether either of these two methods work.
- Goal is to create a new voltage ramp for our cavity rather than the one right now.
- Dark horse: 3rd harmonic cavity that may be available to us.
  - Note: My initial calculations show that it will not work as is. A new tuner will probably need to be built for this, plus, perhaps lowering the Q of the cavity.